

Review of the Greenhouse Effect

EES 3310/5310

Global Climate Change

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Class #7: Monday, February 8 2021

Review of Lapse Rates and Stability

Terminology

- **Environmental Lapse**
 - Measured temperature of actual atmosphere
 - Compares one bit of air at one height with another bit at another height.
 - Changes from one time and place to another.
- **Adiabatic Lapse**
 - Change in a single parcel of air as it moves up or down
 - “**Adiabatic**” means no heat flowing in or out
 - **Adiabatic changes are reversible**
 - **Heat flow** is irreversible

Perspective

- Stable:
 - Environmental lapse \leq adiabatic lapse
- Unstable:
 - Environmental lapse $>$ adiabatic lapse
- Adiabatic lapse:
 - Dry: 10 K/km
 - Moist: 4-8 K/km (depends on humidity)
- Pure radiative equilibrium (Layer models):
 - Would produce lapse of **16 K/km**: unstable
- Radiative-Convective equilibrium:
 - Convection modifies environmental lapse
 - Normal environmental lapse is roughly **6 K/km**
(typical *moist adiabatic lapse rate*)

Band Saturation

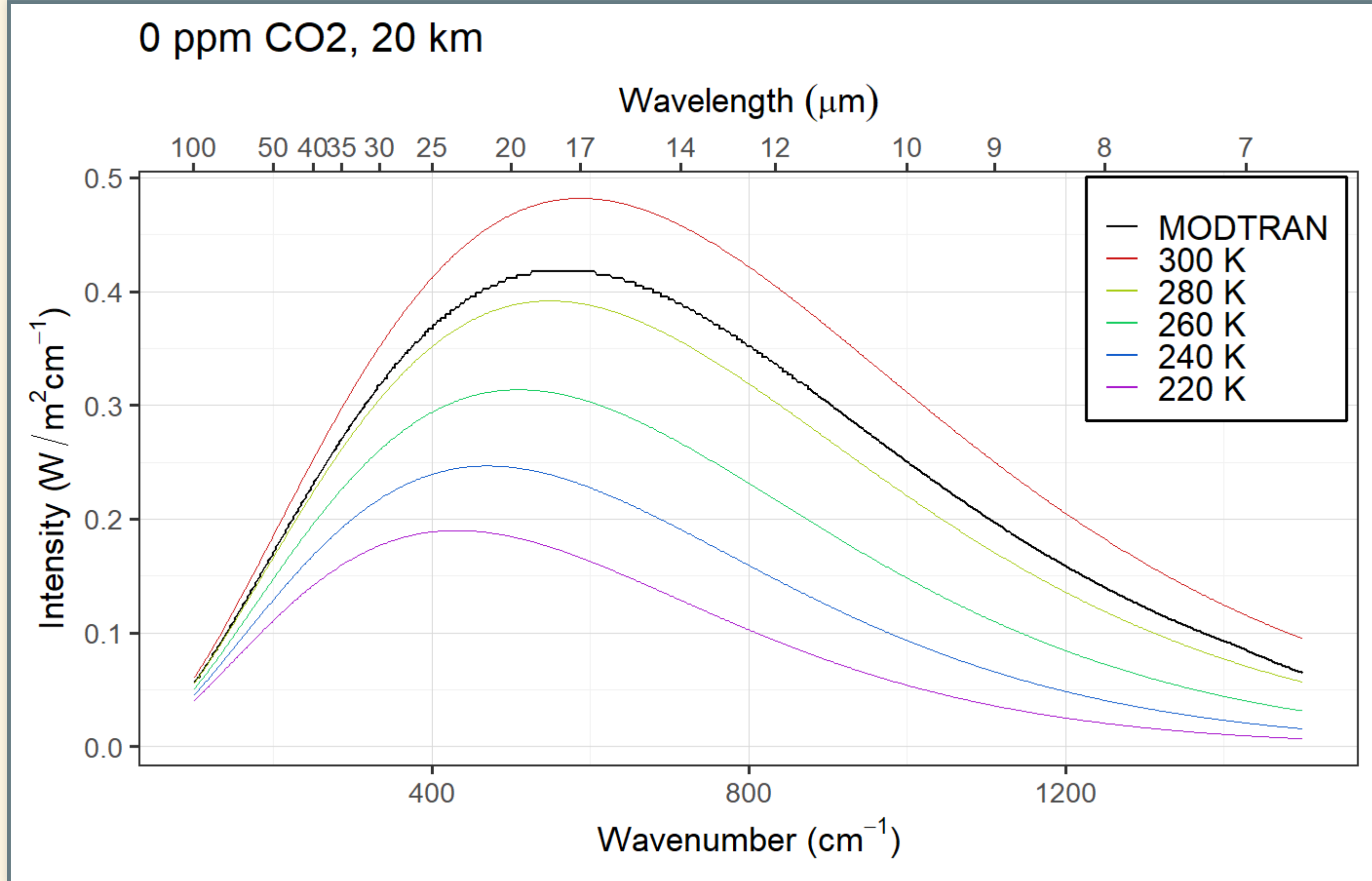
Band Saturation

- Small concentrations of greenhouse gas
 - Small absorption
 - Absorption rises rapidly as more gas is added
 - Doubling the amount of gas doubles the absorption
- Saturation
 - Absorption can't be more than 100%
 - As absorption gets large, adding more gas has a diminishing effect
- “Band” saturation
 - Gases absorb in “bands”
 - Strong absorption in the middle of the band
 - This saturates first
 - Weak absorption on both sides
 - The “wings” of the band
 - These saturate more slowly
 - After the center of the band saturates, the wings gradually become more saturated
 - The saturated region of the spectrum gradually gets wider and wider
 - Total absorption rises by the same amount every time the amount of gas doubles

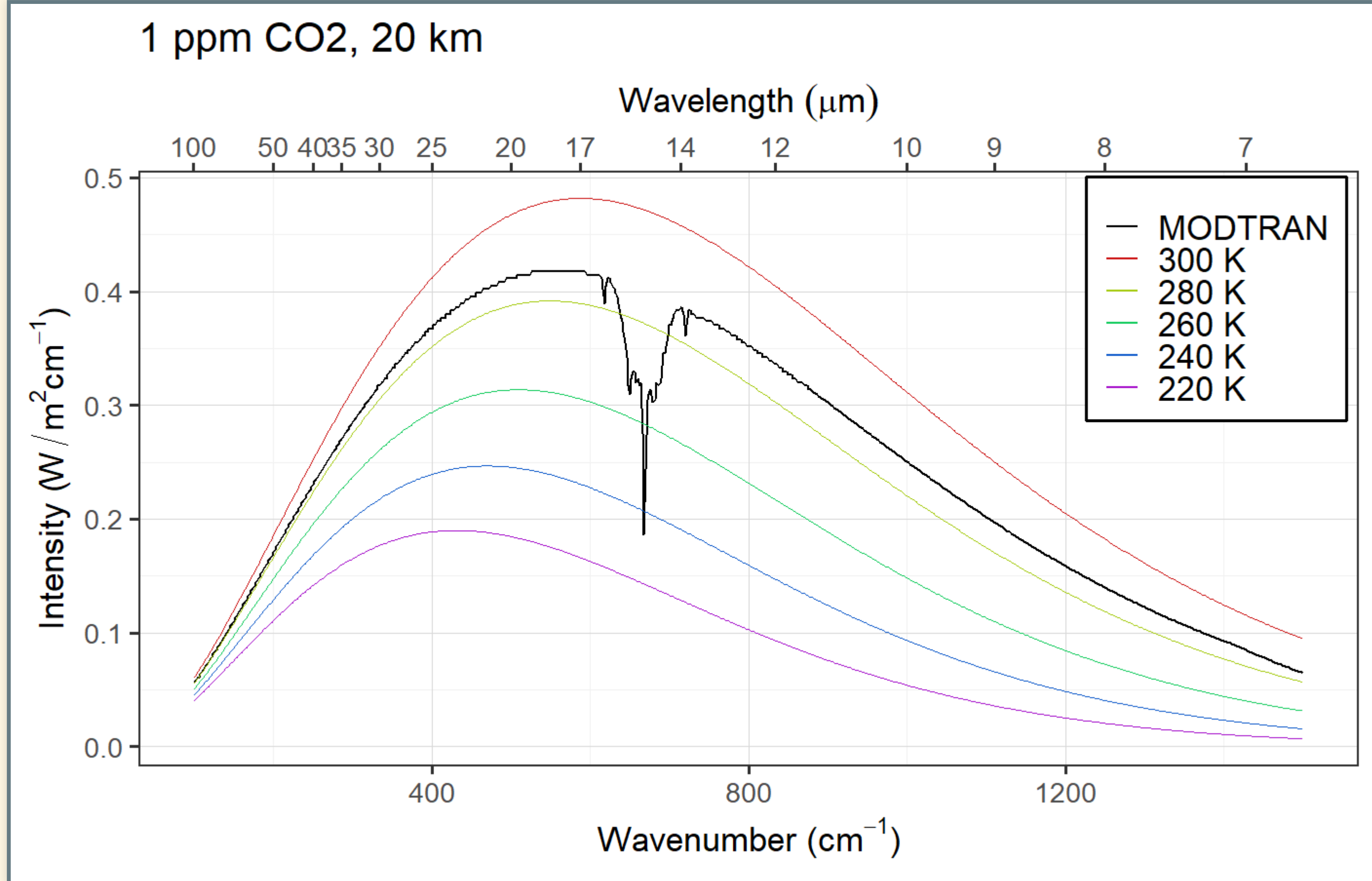
Set up MODTRAN:

- Open MODTRAN <http://climatemodels.uchicago.edu/modtran>
- Set “Location” to “1976 U.S. Standard Atmosphere”.
- Set altitude to 20 km.
- Set all greenhouse gases to zero.

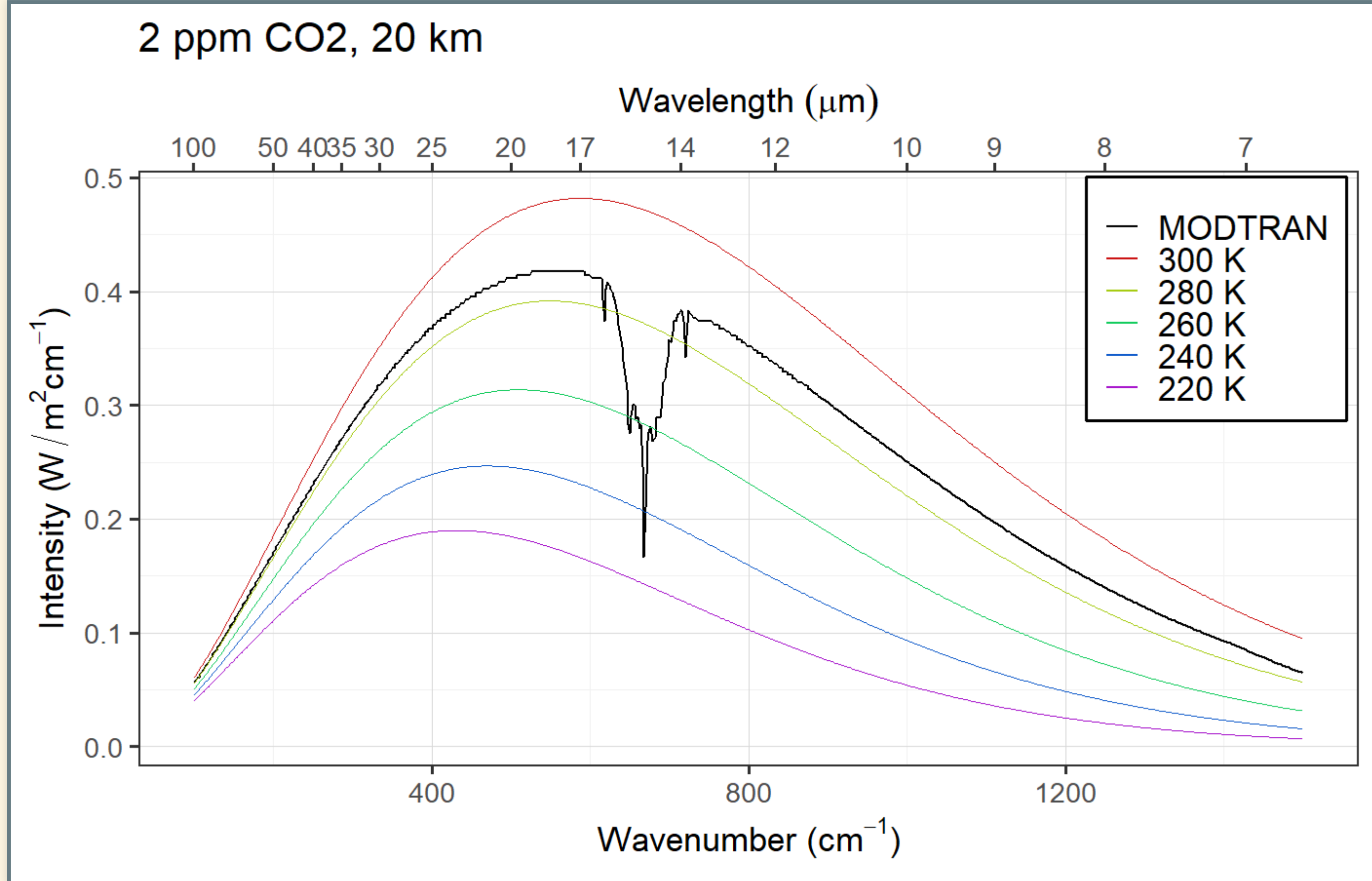
No CO₂



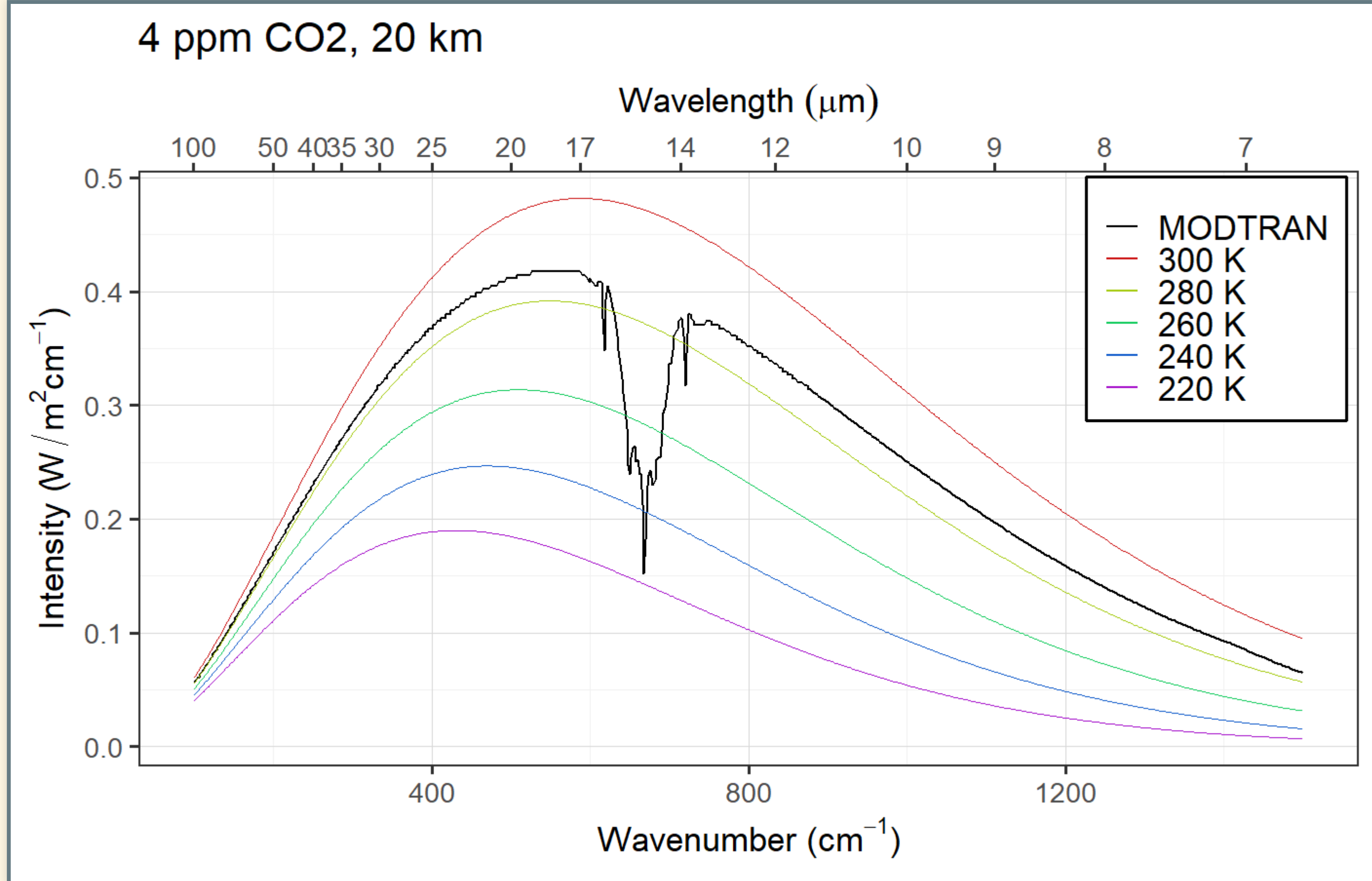
1 ppm CO₂



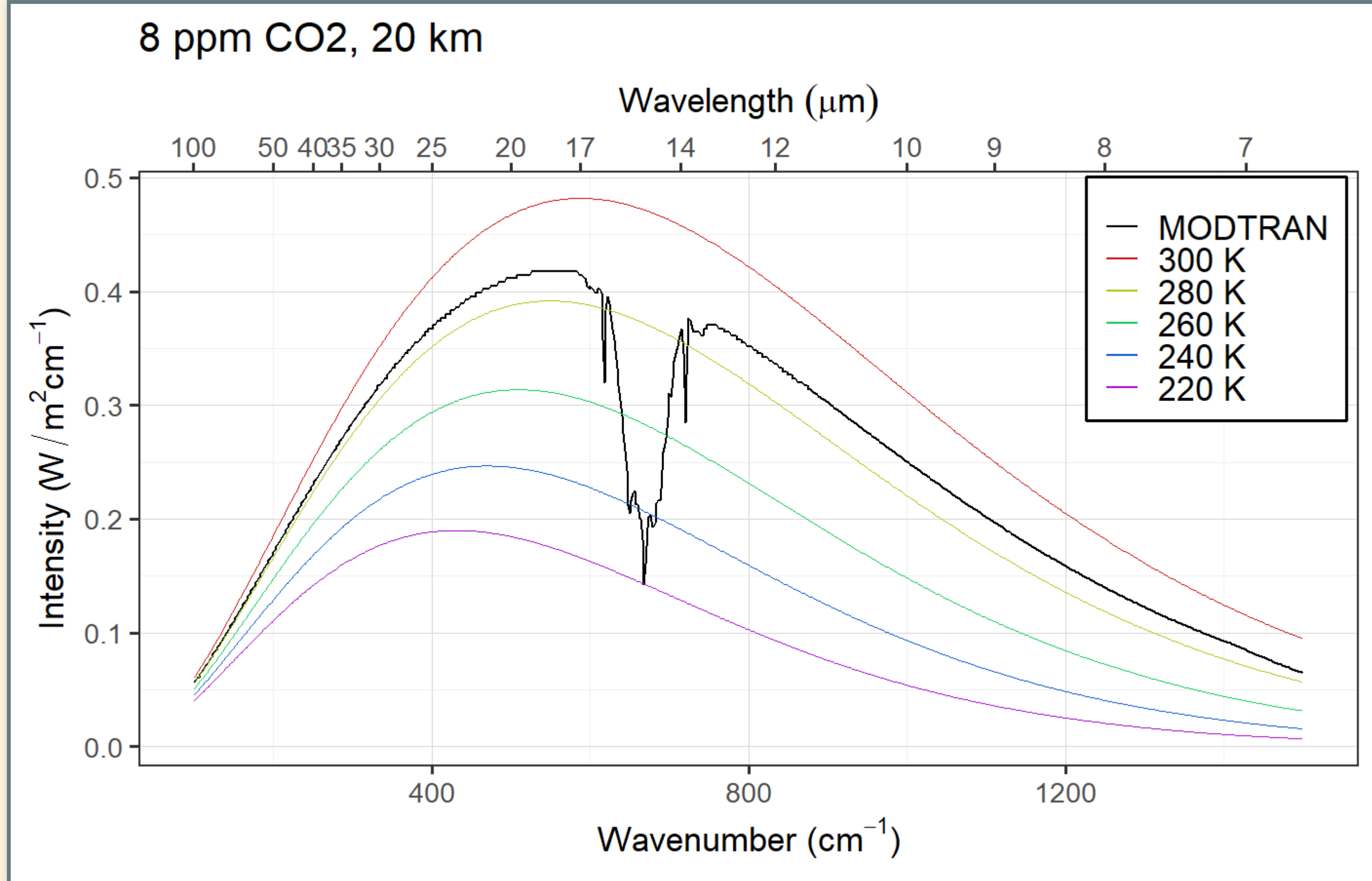
2 ppm CO₂



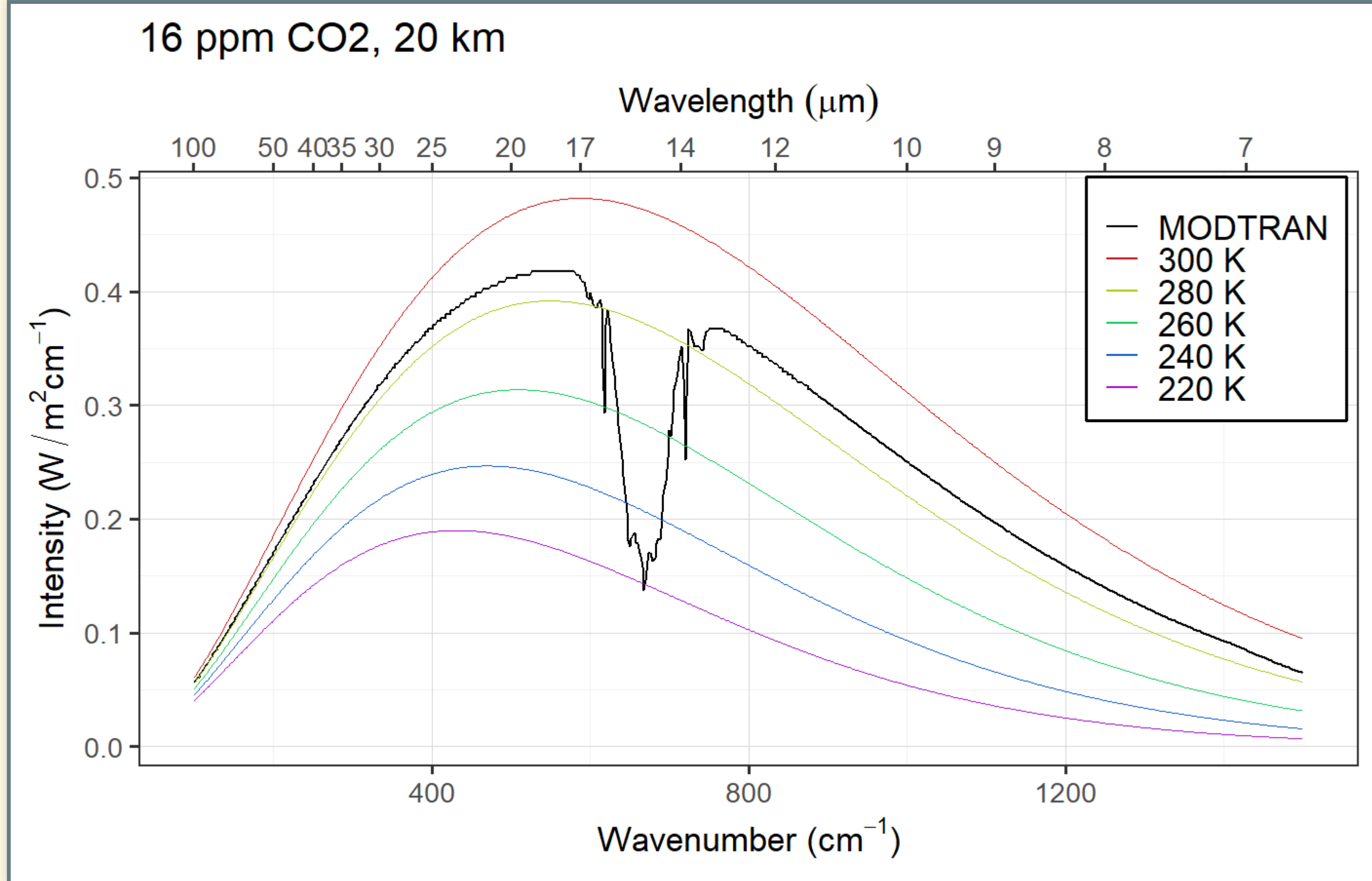
4 ppm CO₂



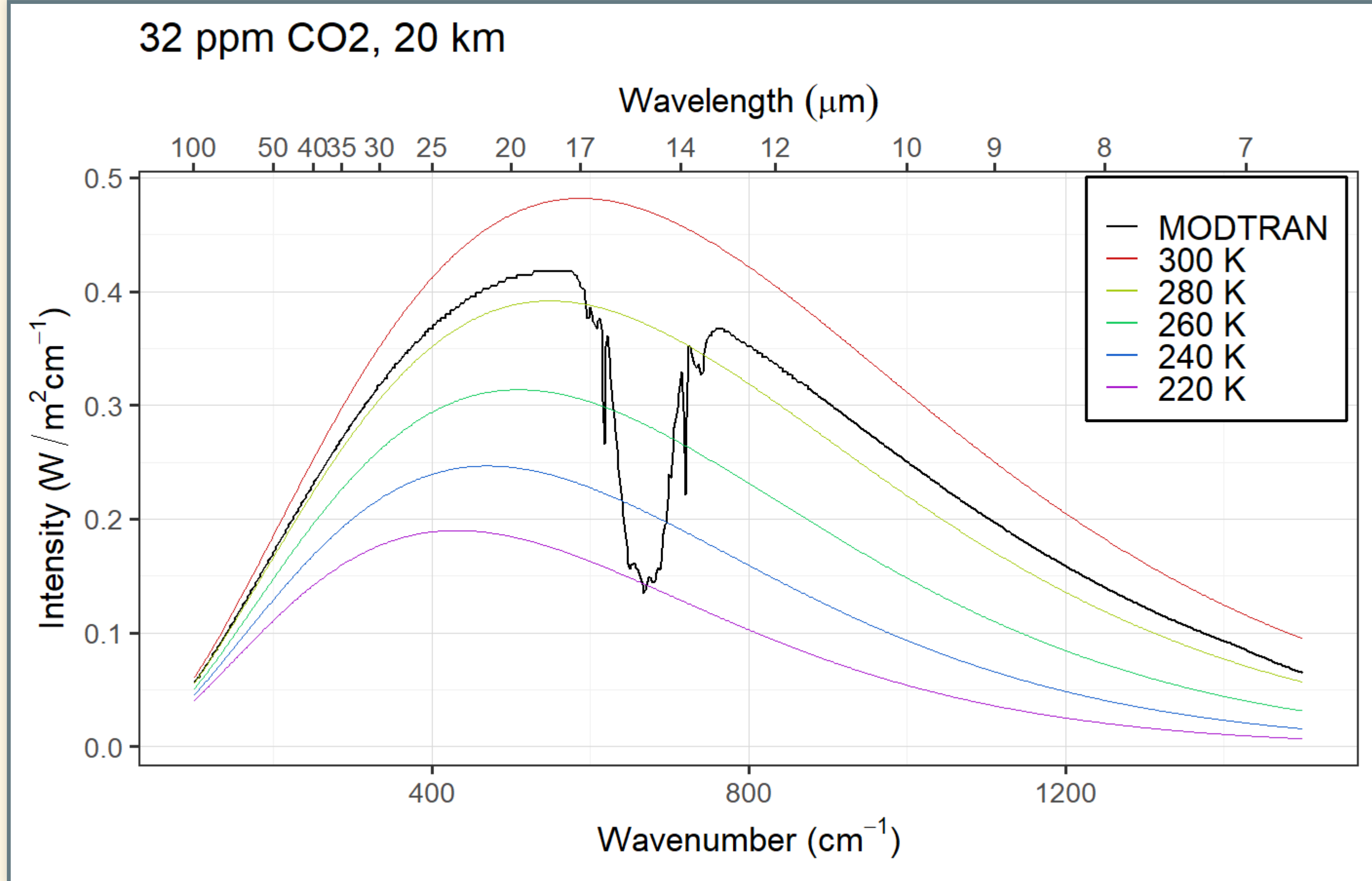
8 ppm CO₂



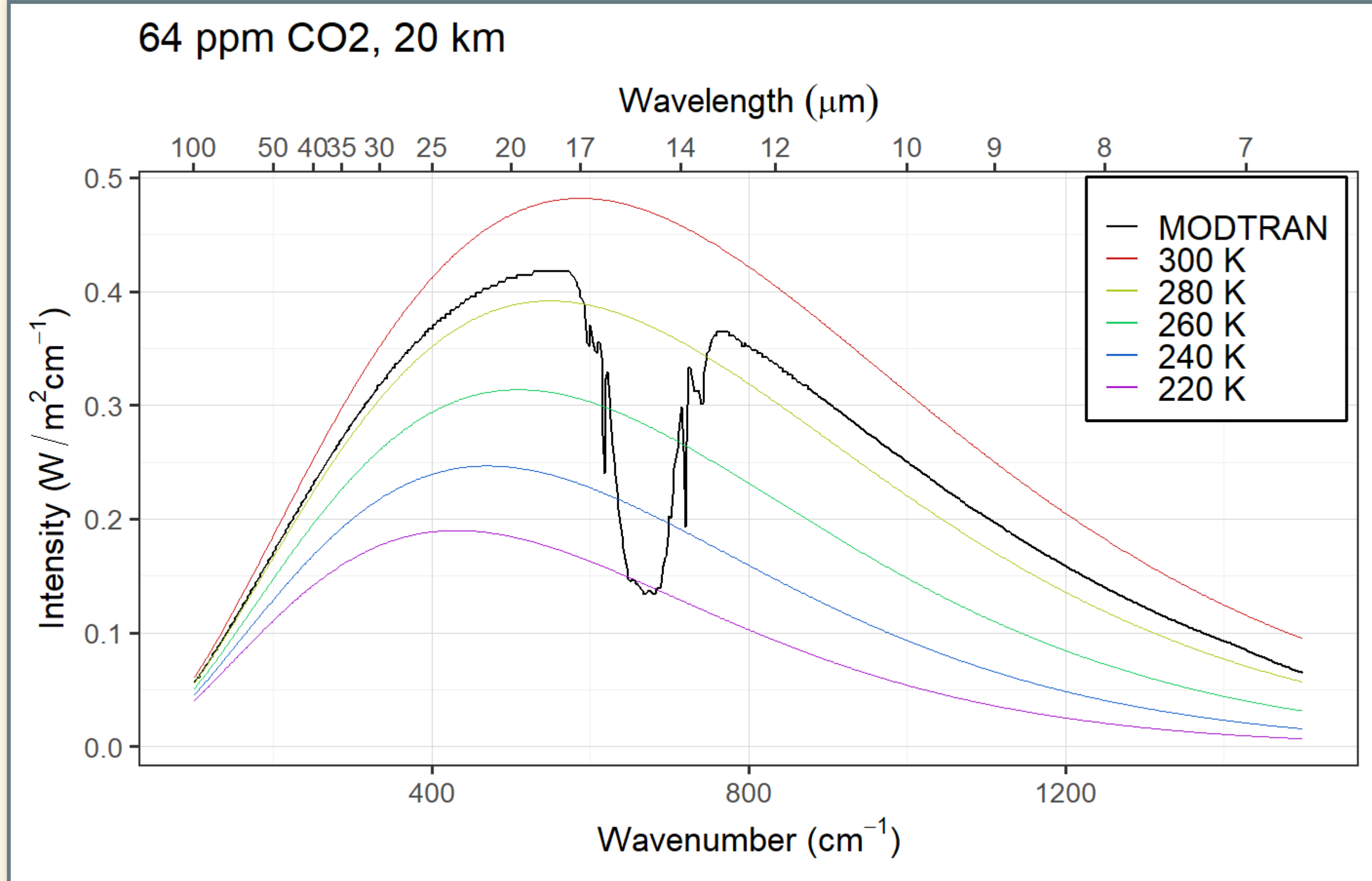
16 ppm CO₂



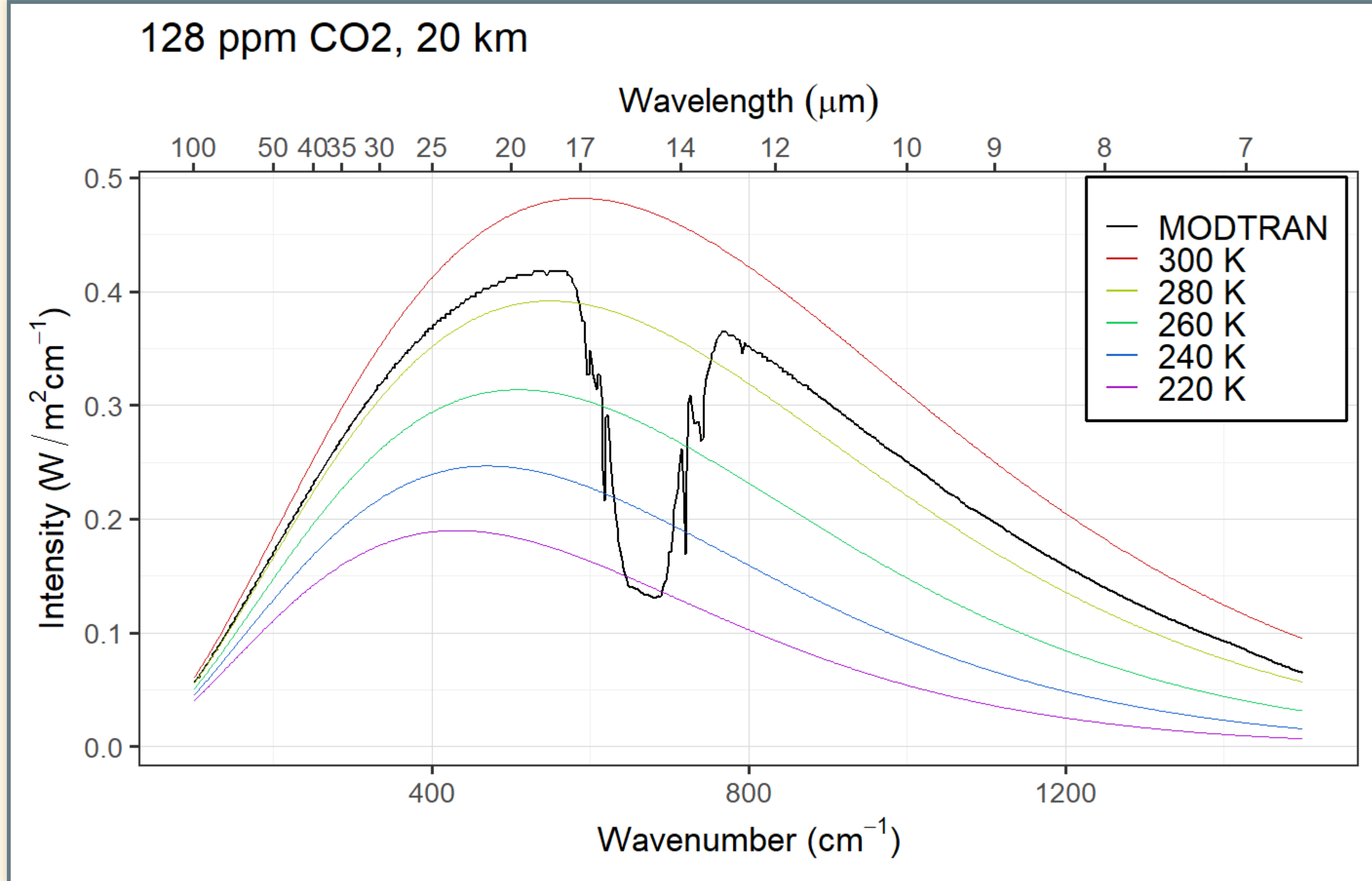
32 ppm CO₂



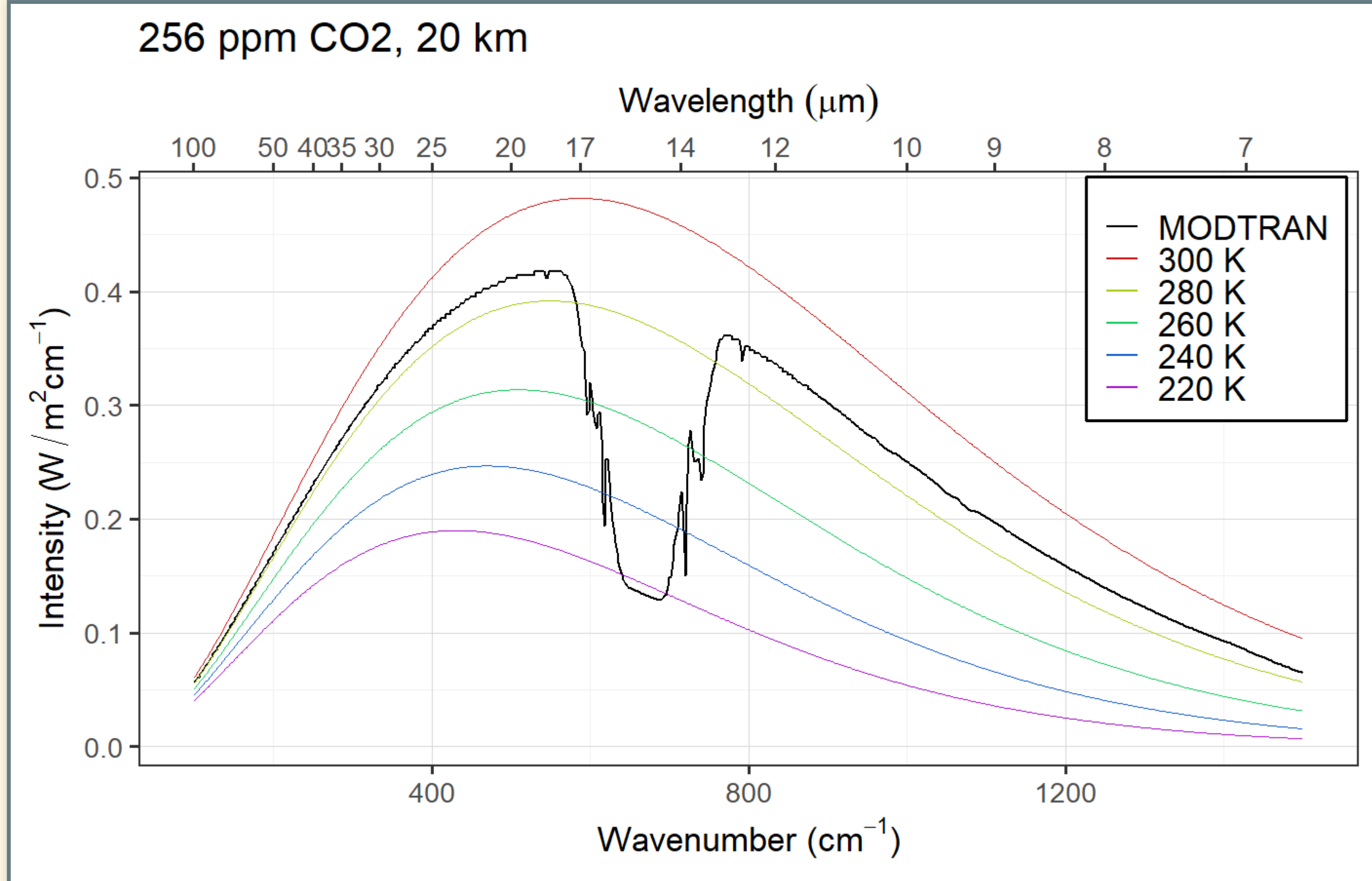
64 ppm CO₂



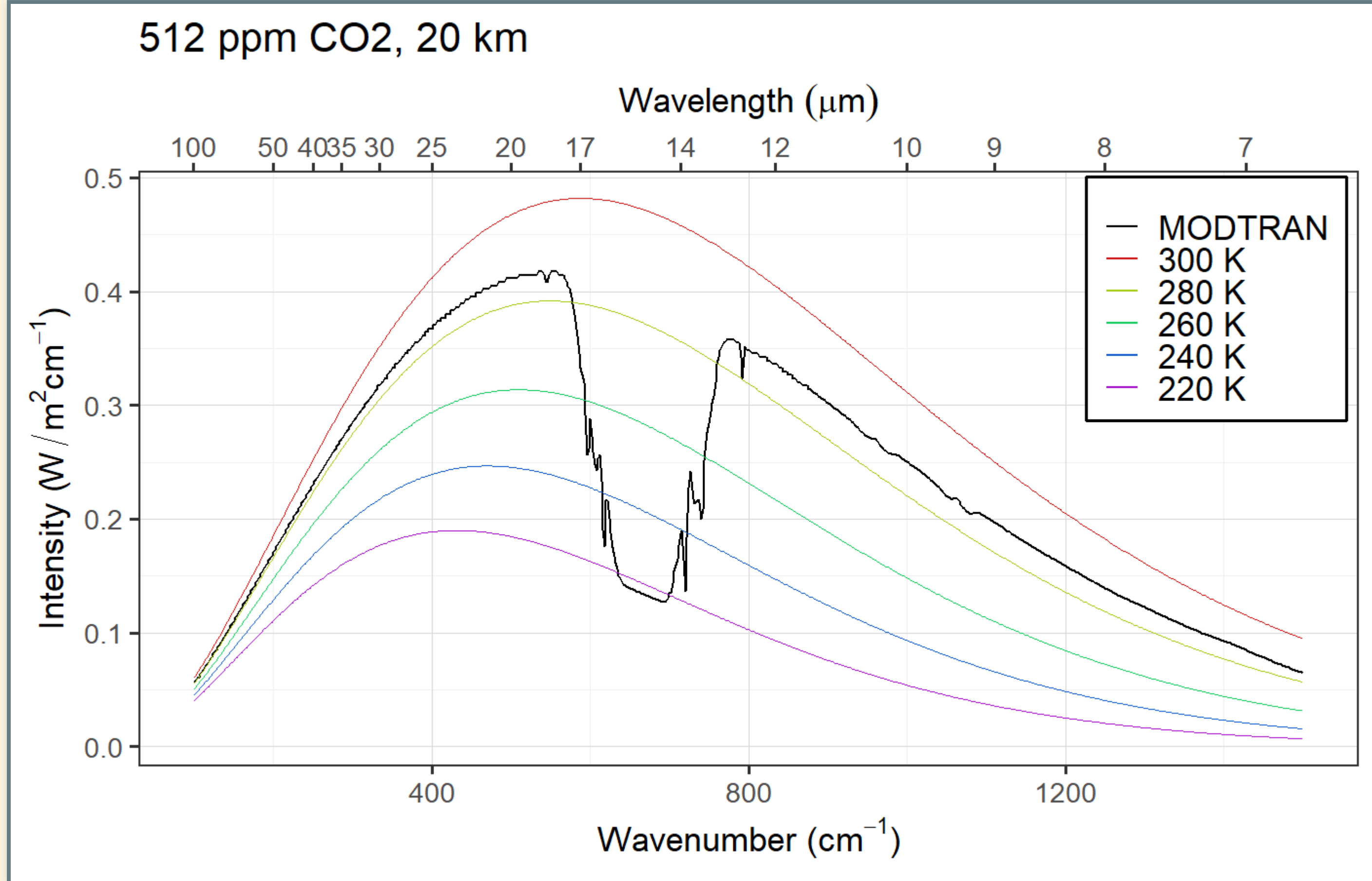
128 ppm CO₂



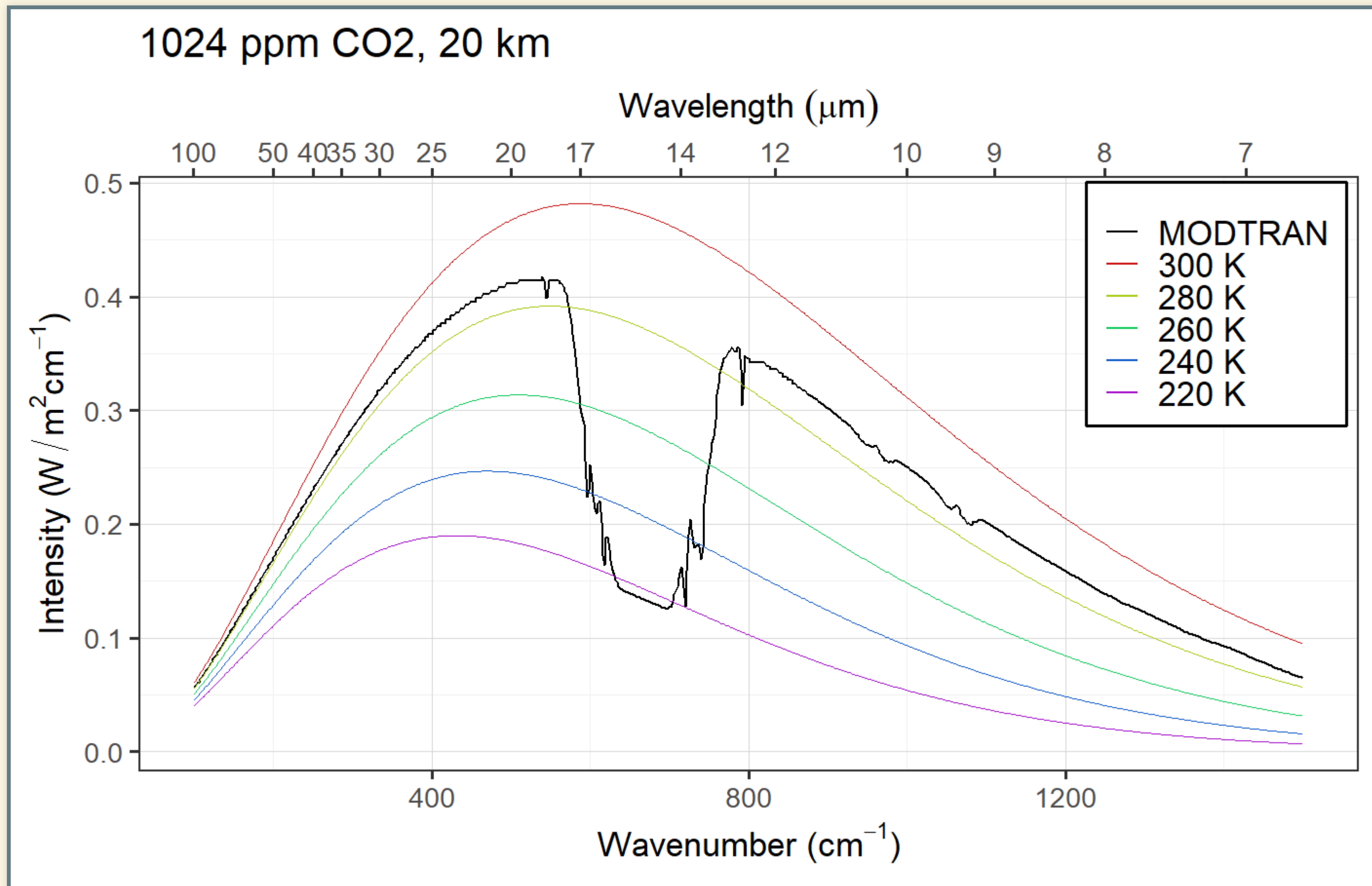
256 ppm CO₂



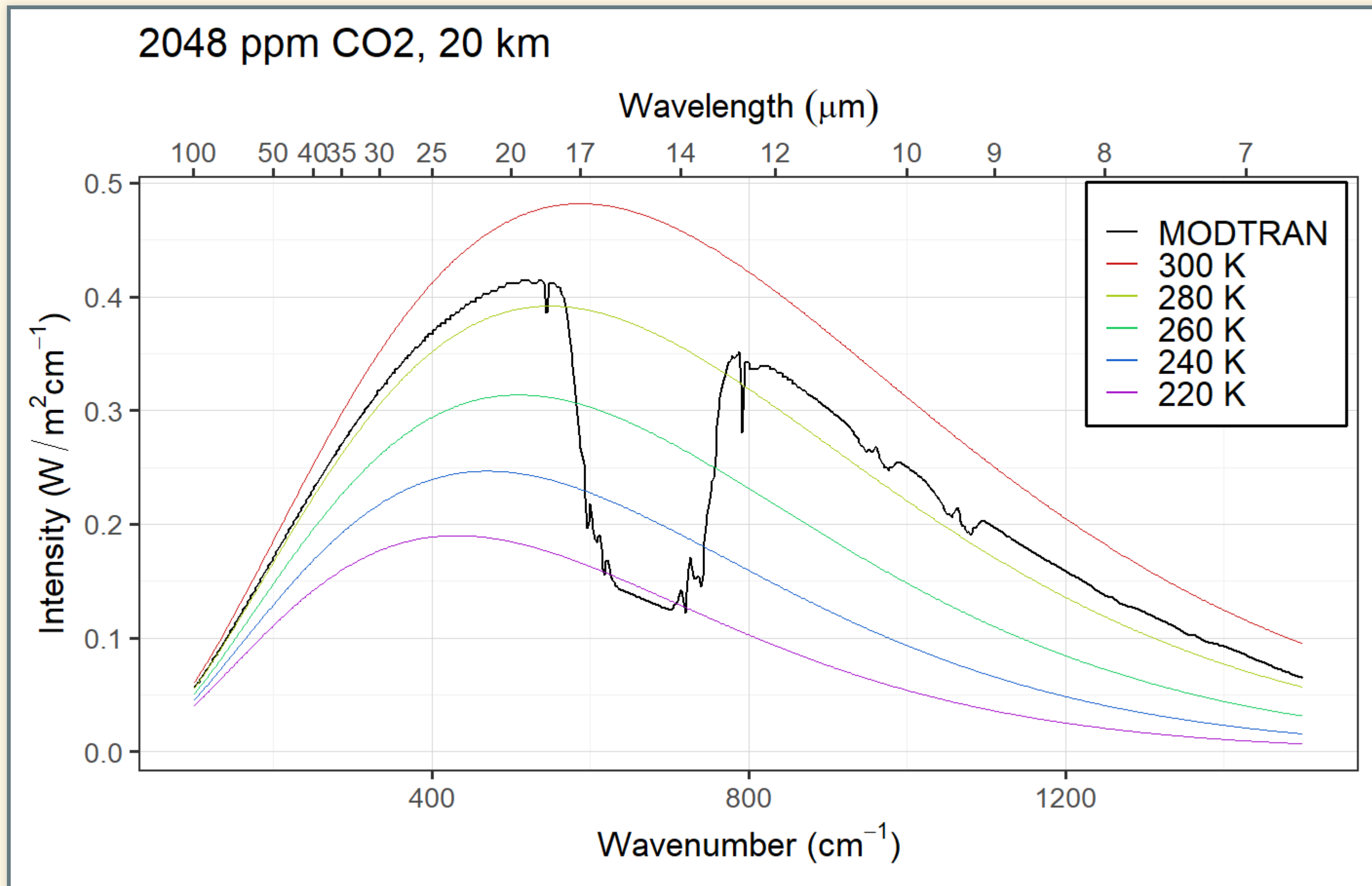
512 ppm CO₂



1024 ppm CO₂



2048 ppm CO₂

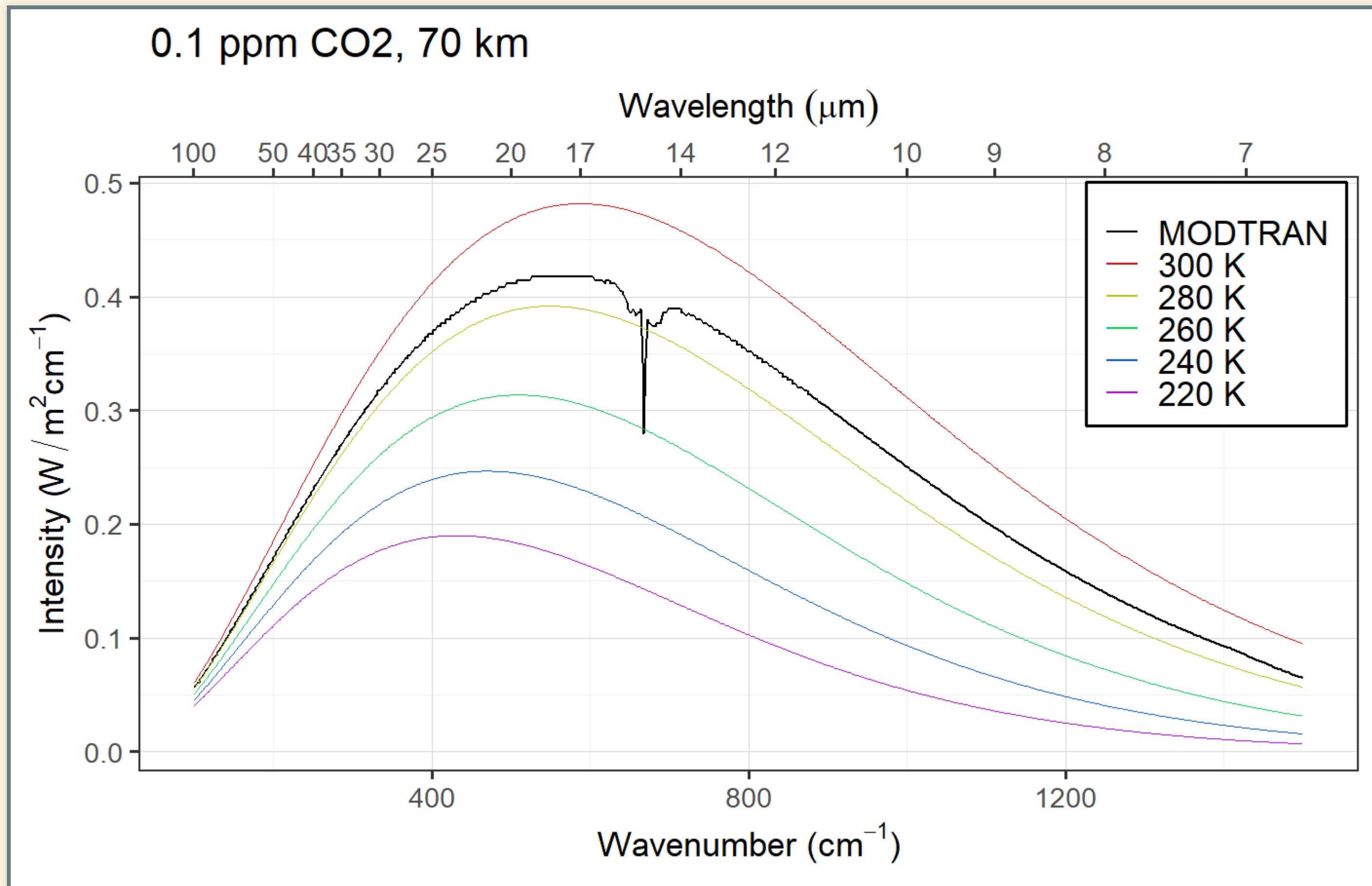


Vertical Structure and Saturation

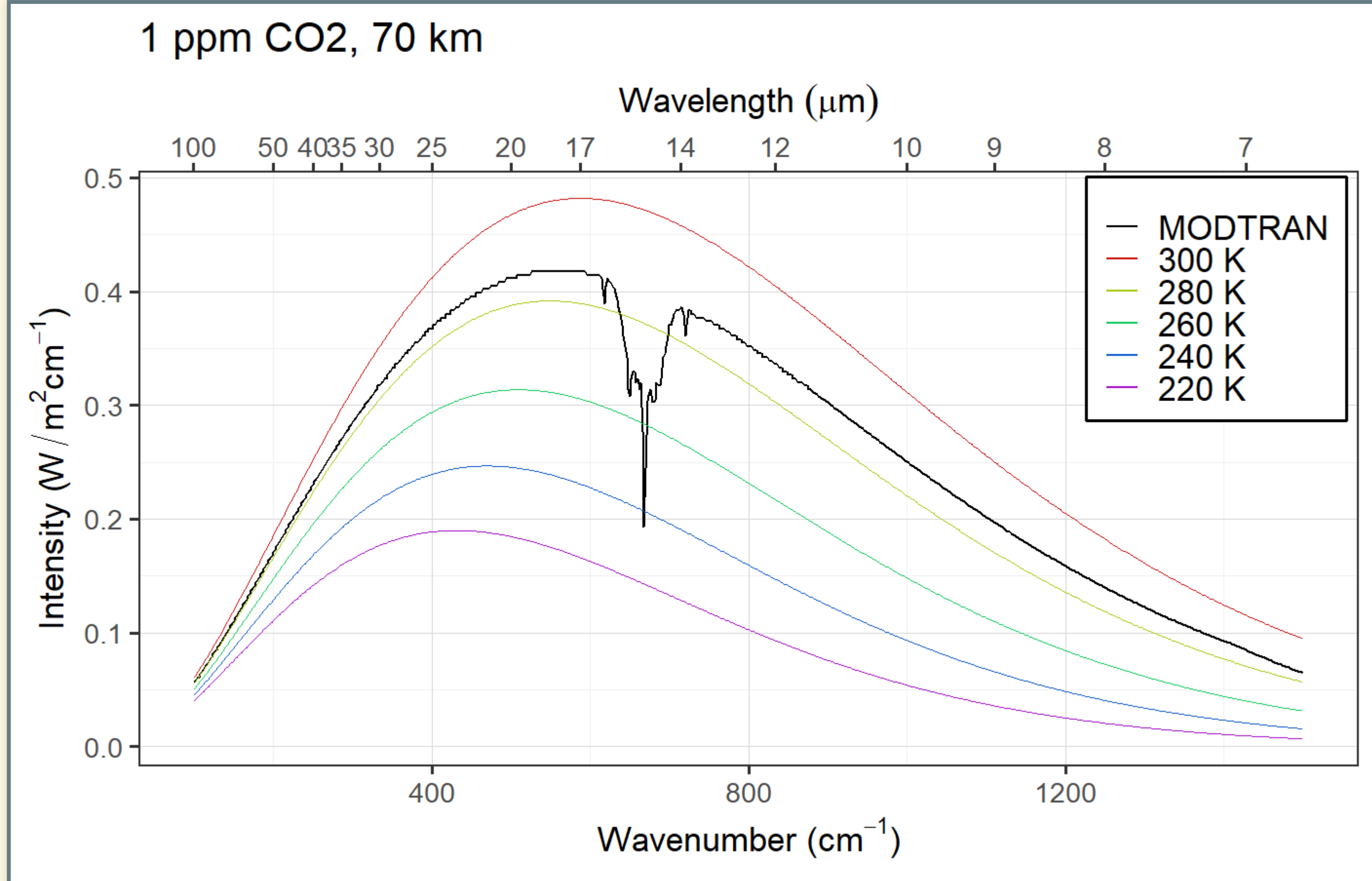
Set up MODTRAN:

- Open MODTRAN <http://climatemodels.uchicago.edu/modtran/>
- Set location to “1976 U.S. Standard Atmosphere”.
- Set altitude to **70 km**.
- Set CO₂ to 0.1 ppm, all other gases to zero.
- Now increase CO₂ by factors of 10 (1, 10, 100, 1000, 10000)
- Notice differences between **70 km** and **20 km**.

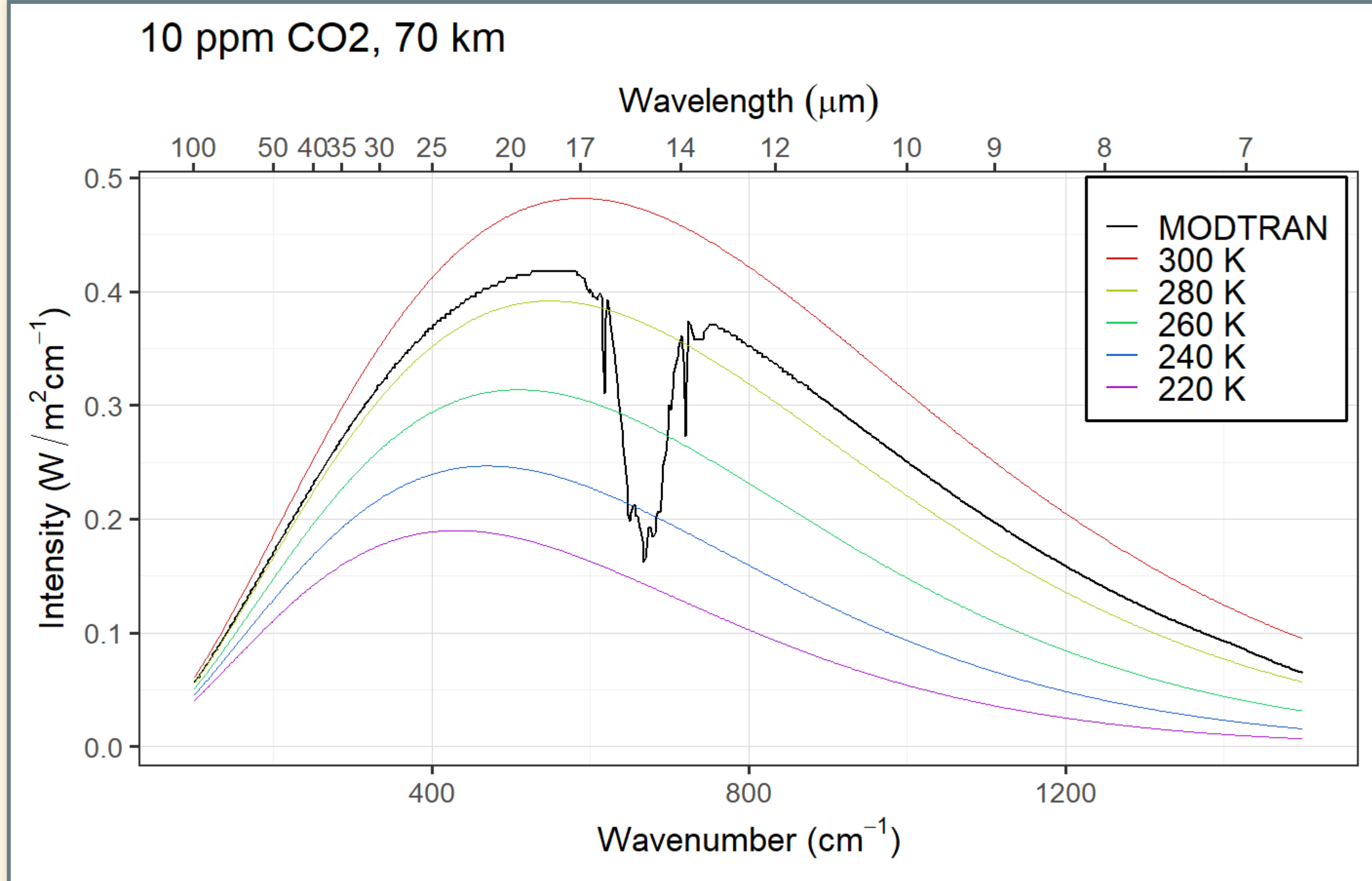
0.1 ppm CO₂



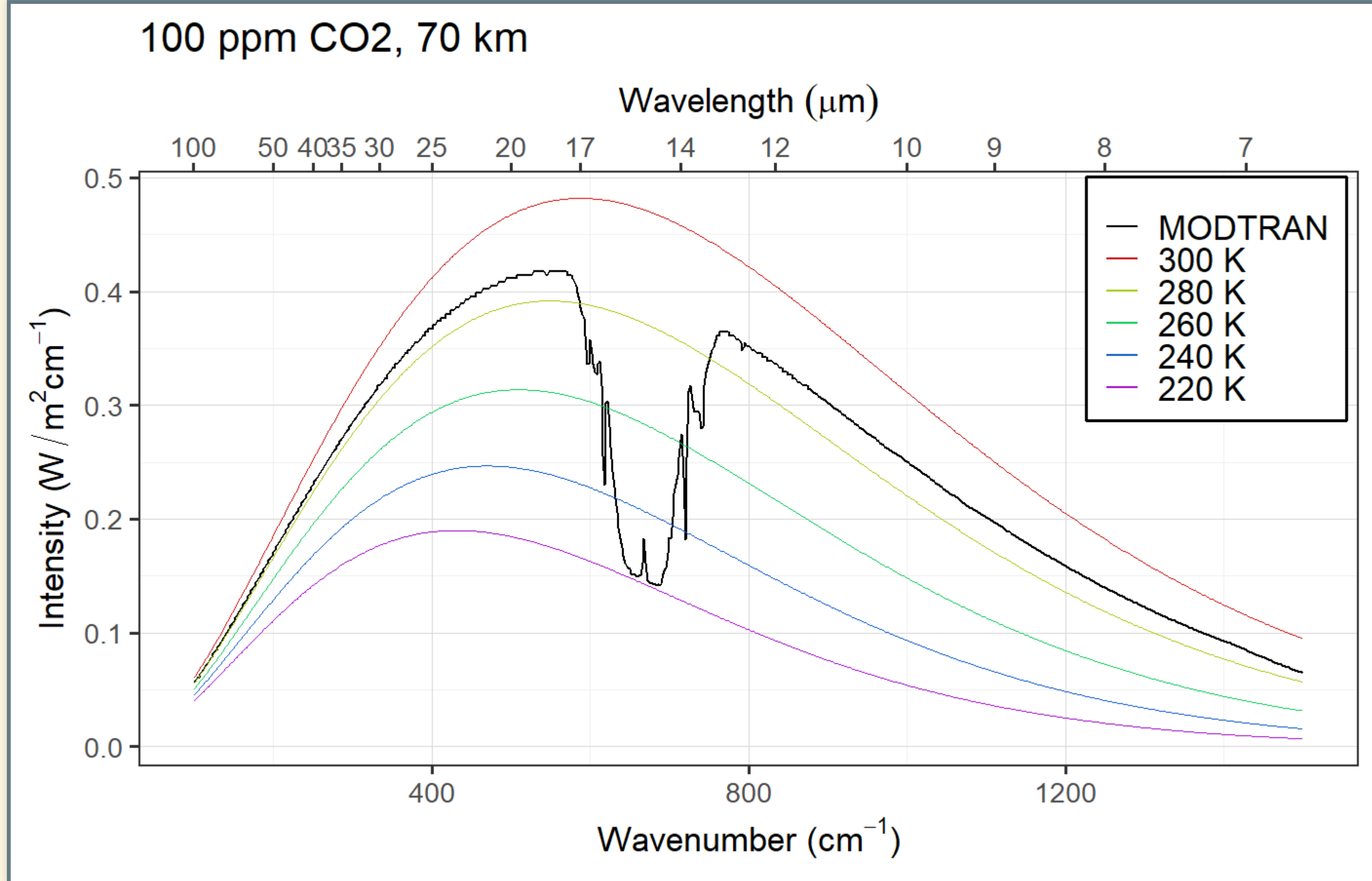
1 ppm CO₂



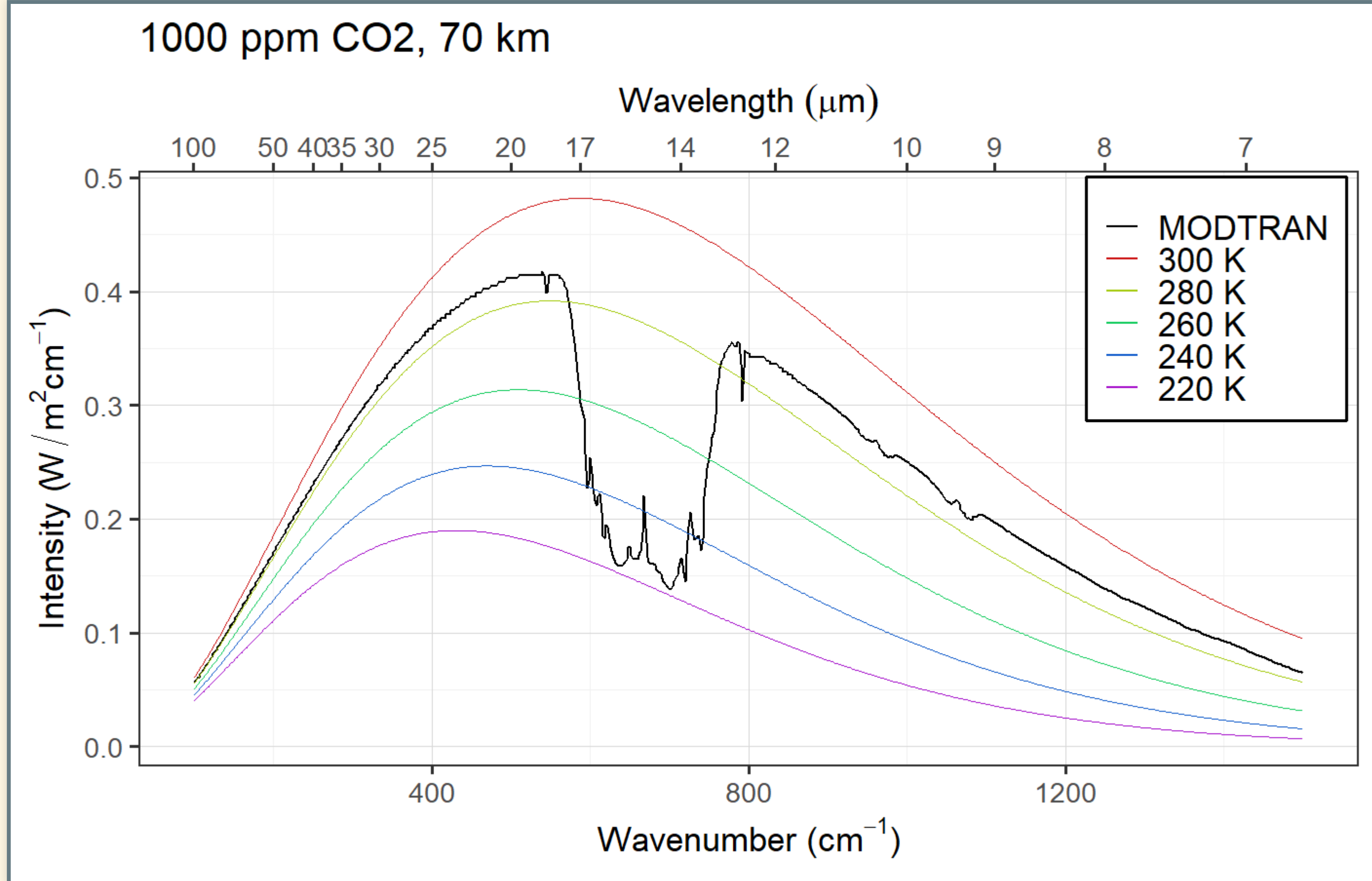
10 ppm CO₂



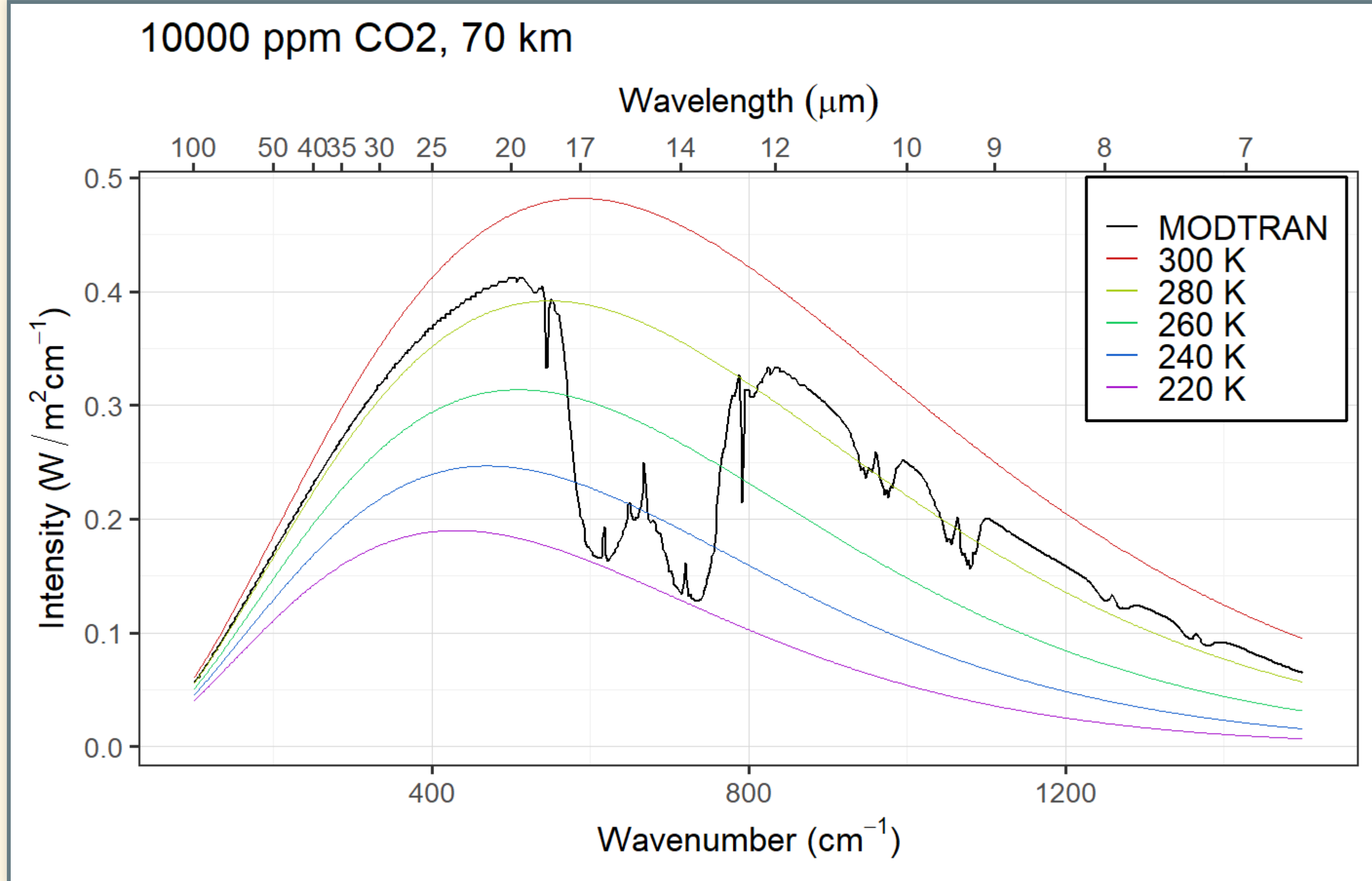
100 ppm CO₂



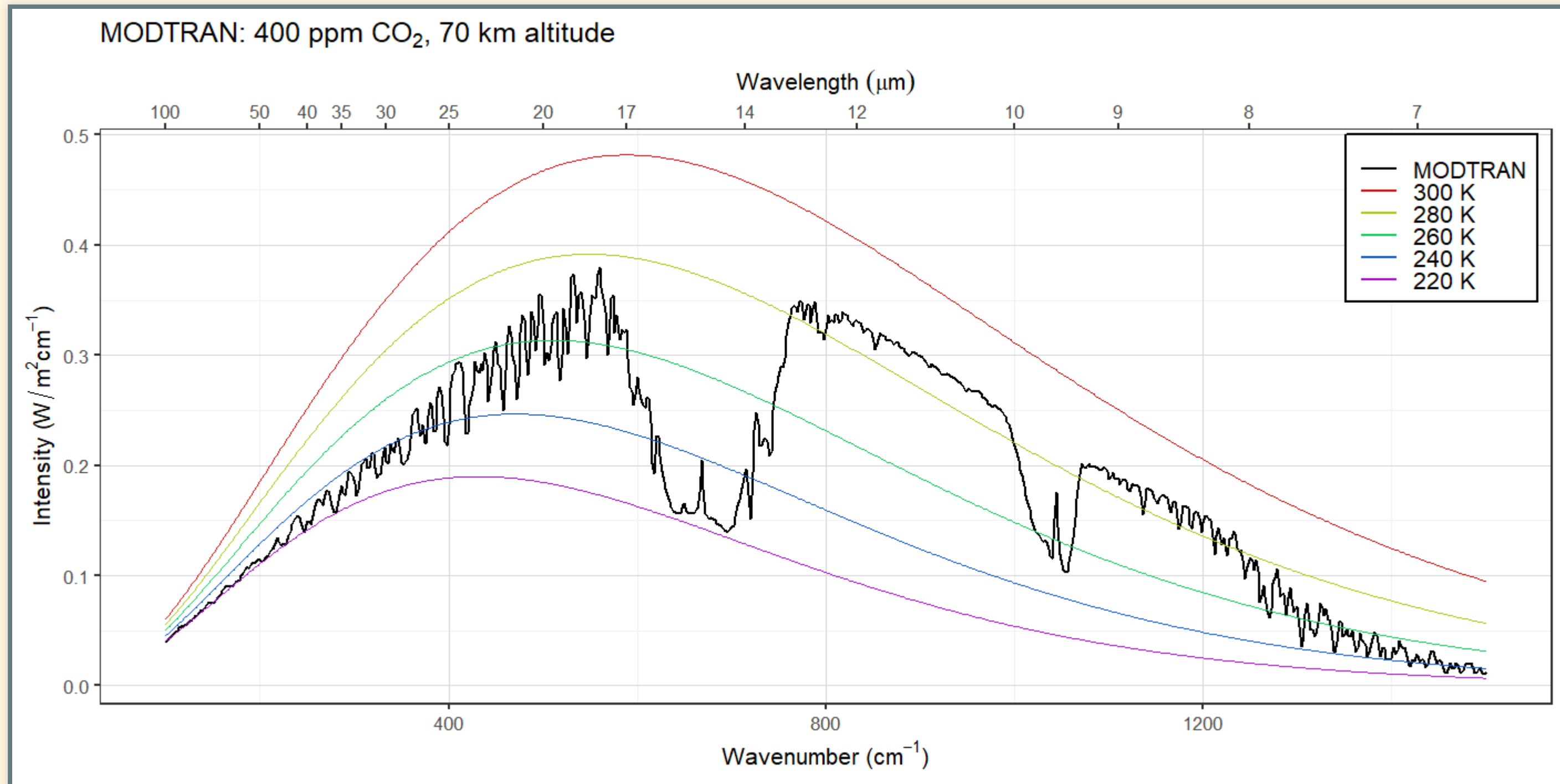
1000 ppm CO₂



10,000 ppm CO₂

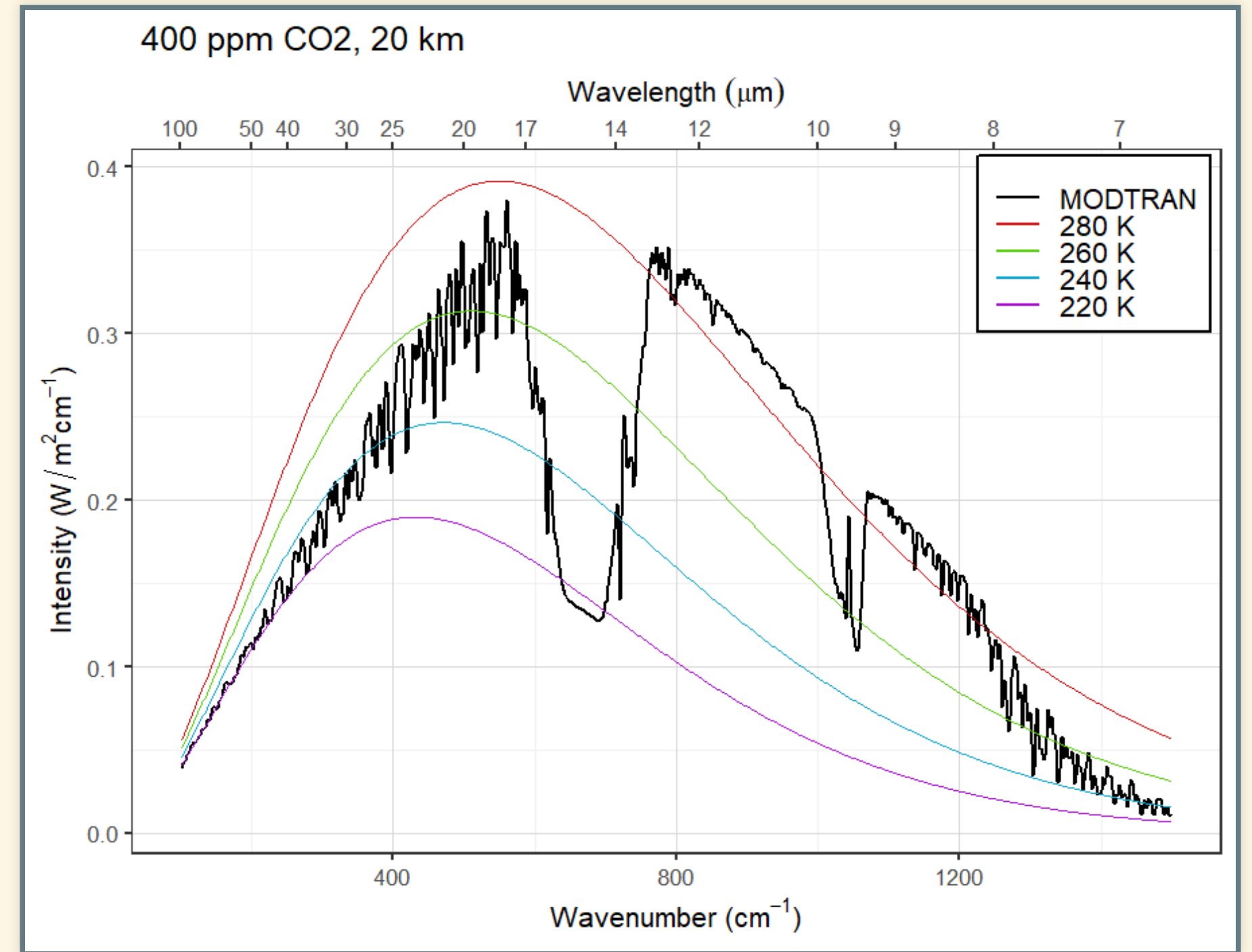
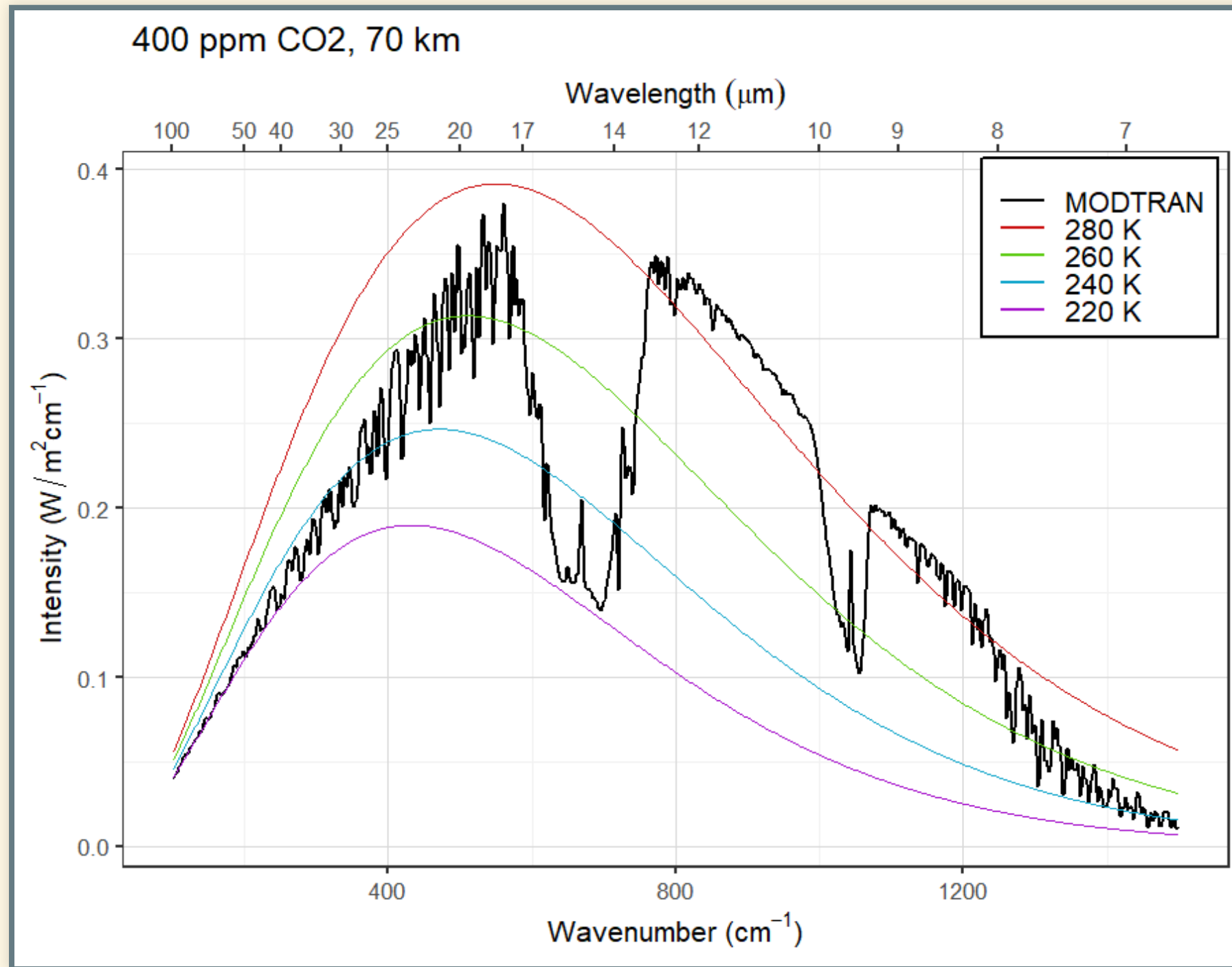


Question

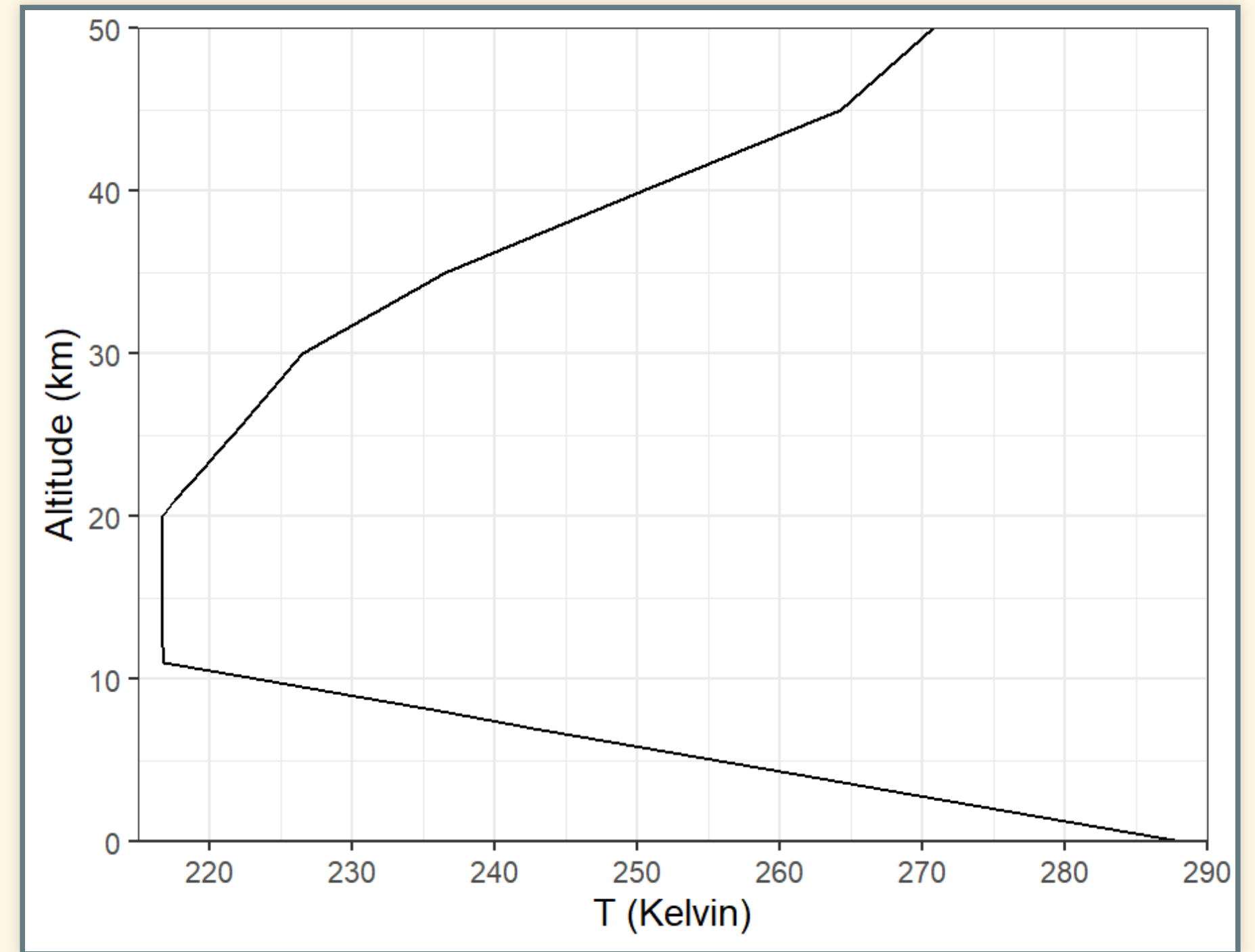
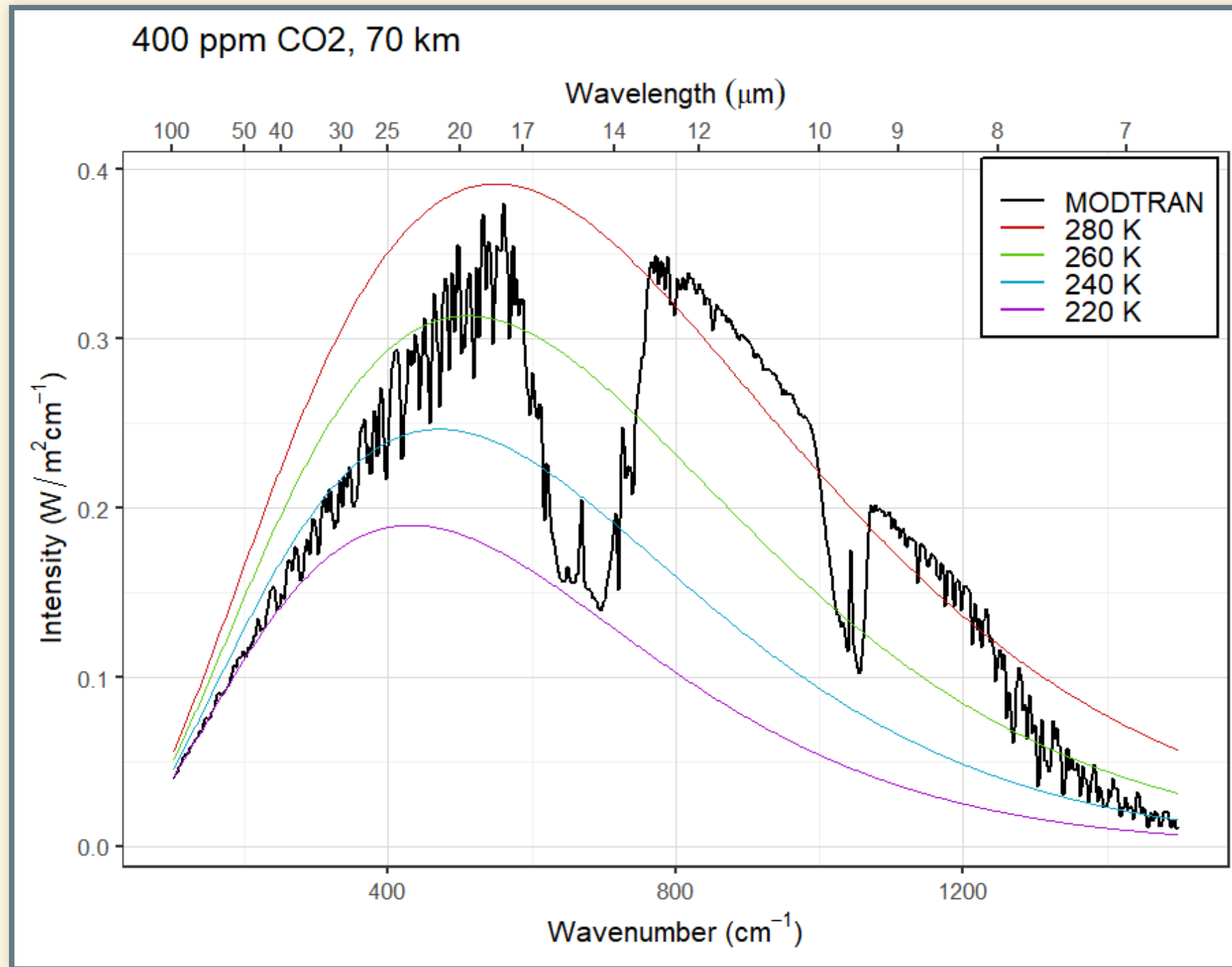


- Why do we see the spike in the middle of the CO₂ absorption feature?

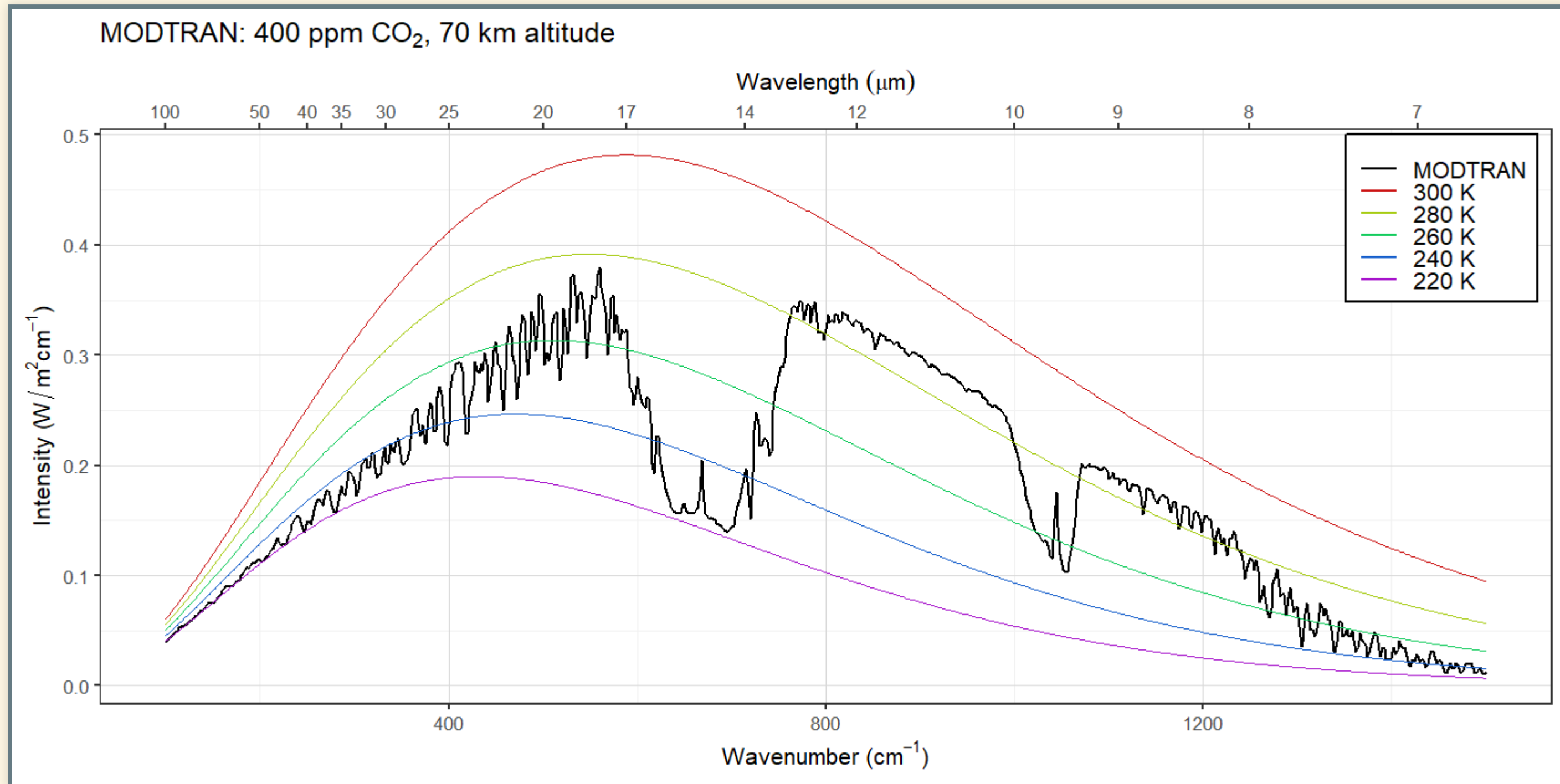
Answer



Answer

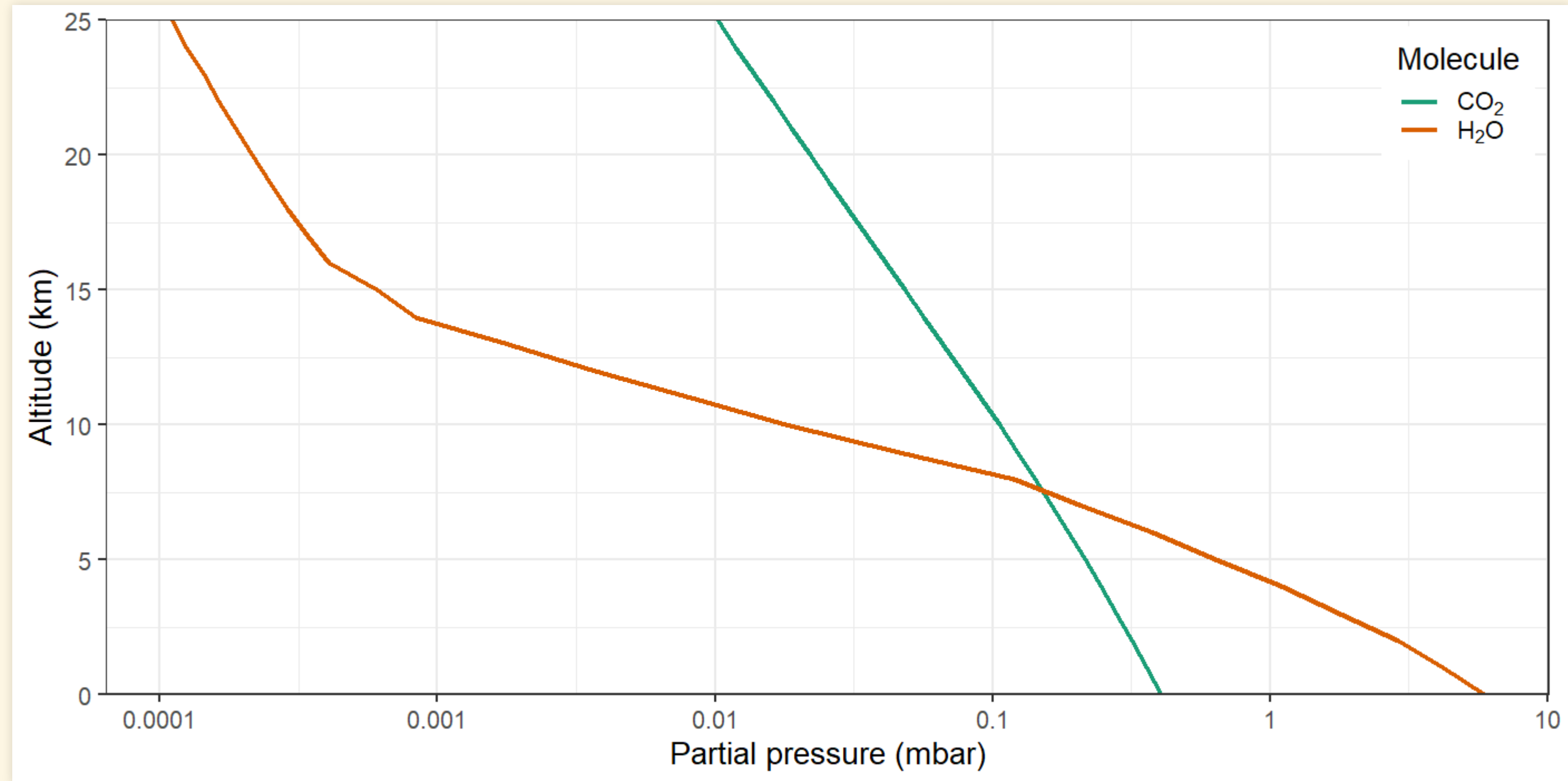


Question



- Water vapor absorption is completely saturated.
 - Why does water vapor emit at warmer temperatures than CO₂?

Answer



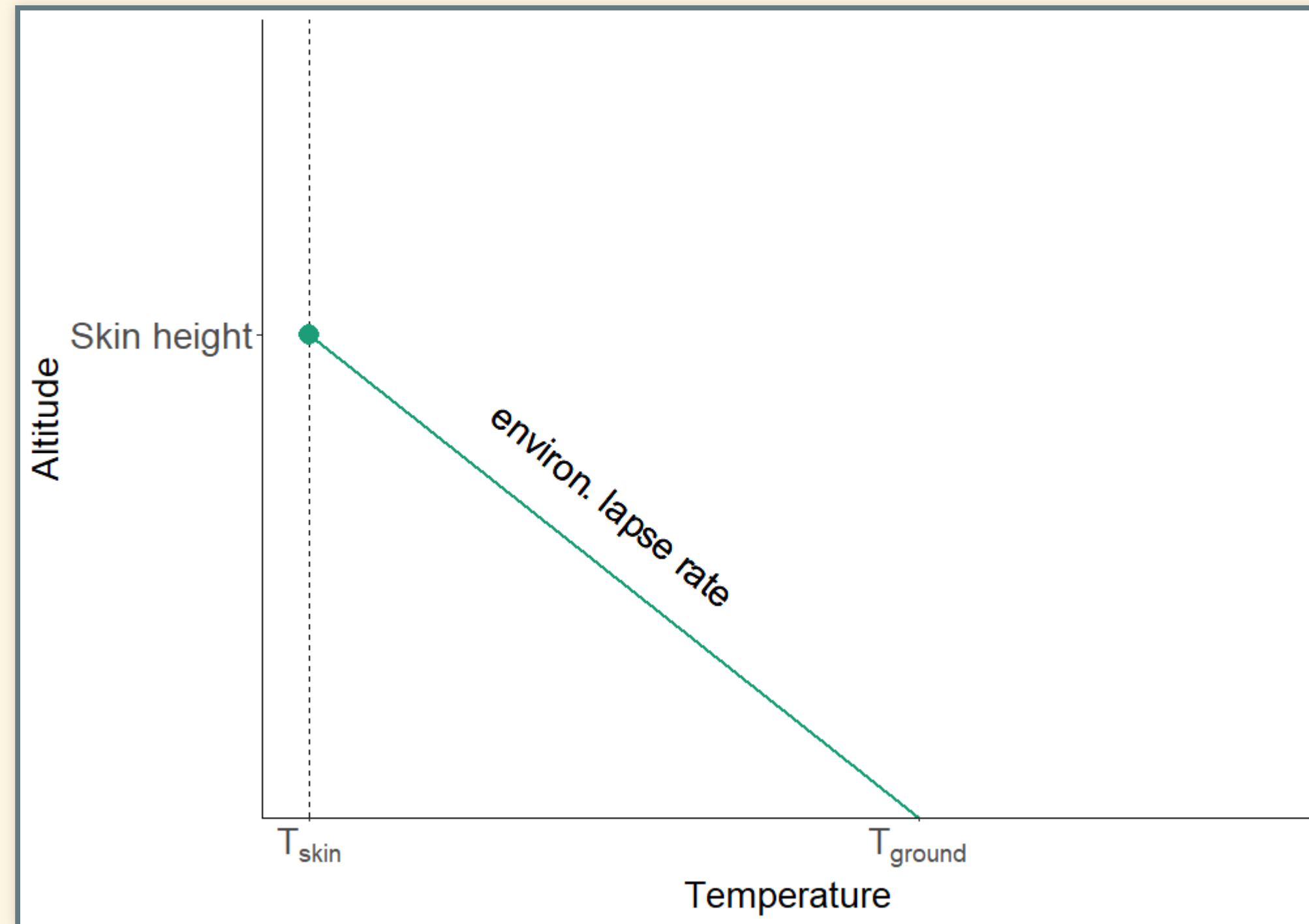
- Near the ground, there is much more water vapor (15 times more)
- Above about 7 km, there is much more CO₂ (100 times more at 20 km)
 - Water vapor concentrations become small enough to be transparent to space at a much lower altitude than CO₂

Convection and the Greenhouse Effect

Another Perspective on Band Saturation

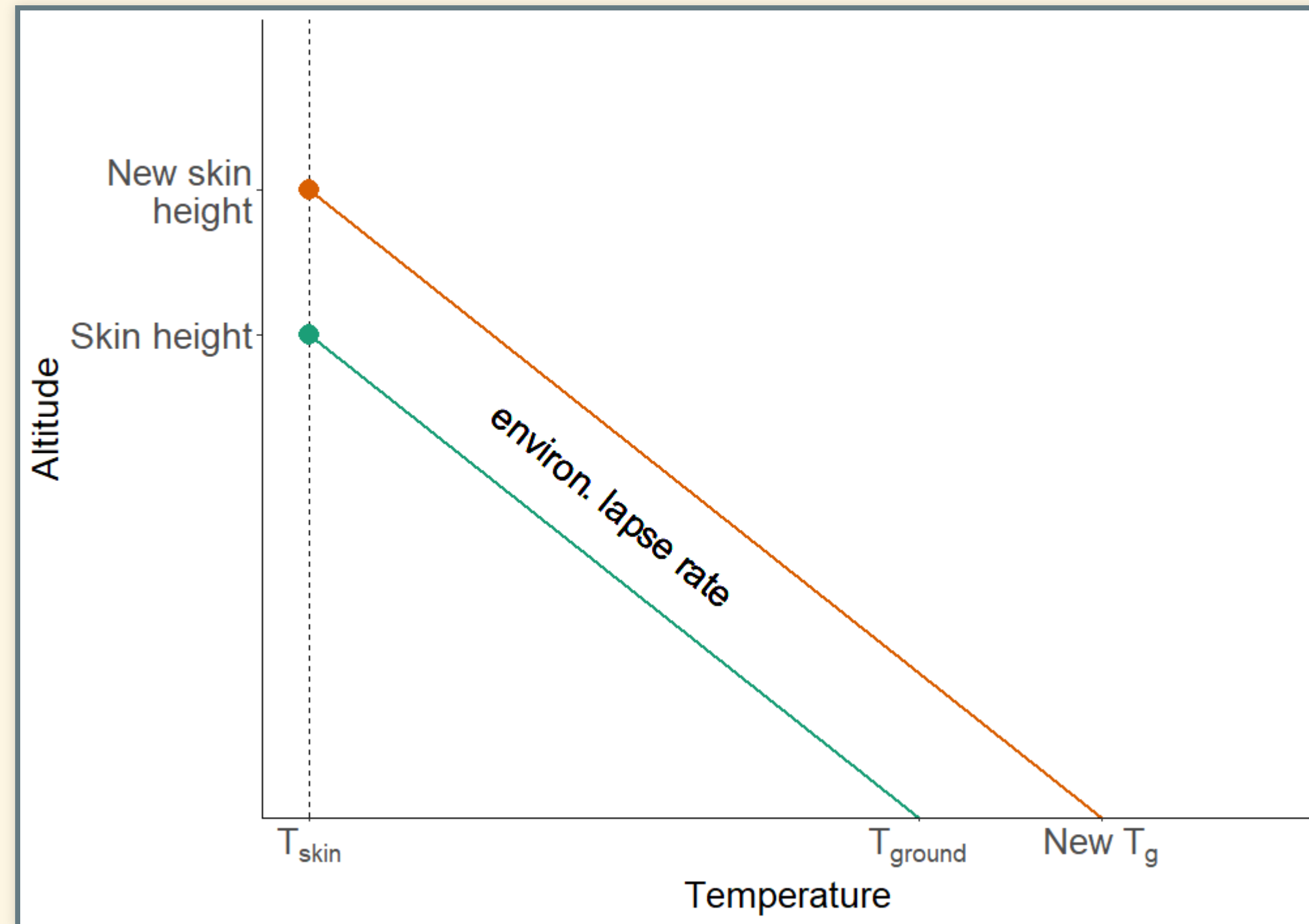
- Instead of thinking of saturation as increasing absorption ...
- Think of saturation as raising the skin height
 - Skin height = the height at which the atmosphere becomes transparent enough to radiate out to space
 - The height of the top of the atmospheric layer in a layer model
 - The atmosphere becomes opaque at a certain wavelength when there are more than a certain number of molecules per square meter of an absorbing gas overhead.
 - The higher you go, the fewer molecules are overhead and the more are below your feet.
 - The atmosphere gradually becomes more transparent, but we pretend that this happens suddenly at a certain height.
 - Pressure and density fall exponentially as you go higher, so this approximation is reasonable.
- After band saturation sets in, adding more greenhouse gas raises the skin height.

Saturation, Convection, and the Greenhouse Effect



- Skin temp: $T_{\text{skin}} = T_{\text{bare rock}} = 254 \text{ K}$.
- Ground temp: $T_{\text{ground}} = T_{\text{skin}} + h_{\text{skin}} \times \text{ELR}$
 - ELR = Environmental Lapse Rate

Global warming



- Greater $\text{CO}_2 \rightarrow$ greater skin height.
- Warming: $\Delta T_{\text{ground}} = \Delta h_{\text{skin}} \times \text{env. lapse}$

Review of the Greenhouse Effect

Review of the Greenhouse Effect

1. Start with bare-rock temperature

- This becomes skin temperature

2. Add simple layer atmosphere:

- Completely black to longwave radiation
- Top of atmosphere: skin temperature (same as bare-rock)
- Atmosphere insulates surface \Rightarrow surface heats up
- More layers \Rightarrow bigger greenhouse effect

3. Realistic longwave absorption:

- Atmosphere is not black
- Absorption depends on wavelength

4. Radiative-Convective equilibrium:

- Pure radiative equilibrium would have *huge* environmental lapse rate
 - 16 K/km
- Big lapse rate is unstable \Rightarrow convection
 - ELR (16 K/km) > ALR (6–10 K/km)
 - Convection mixes hot & cold air \Rightarrow reduces environmental lapse until it becomes stable
 - Reduces greenhouse effect
- **Alternate perspective:**
 - Think of greenhouse effect in terms of raising the skin height instead of blocking heat flow.
 - T_{skin} is always $T_{\text{bare rock}}$
 - $T_{\text{ground}} = T_{\text{skin}} + h_{\text{skin}} \times \text{Environmental Lapse Rate}$

Questions & Discussion of Greenhouse Effect